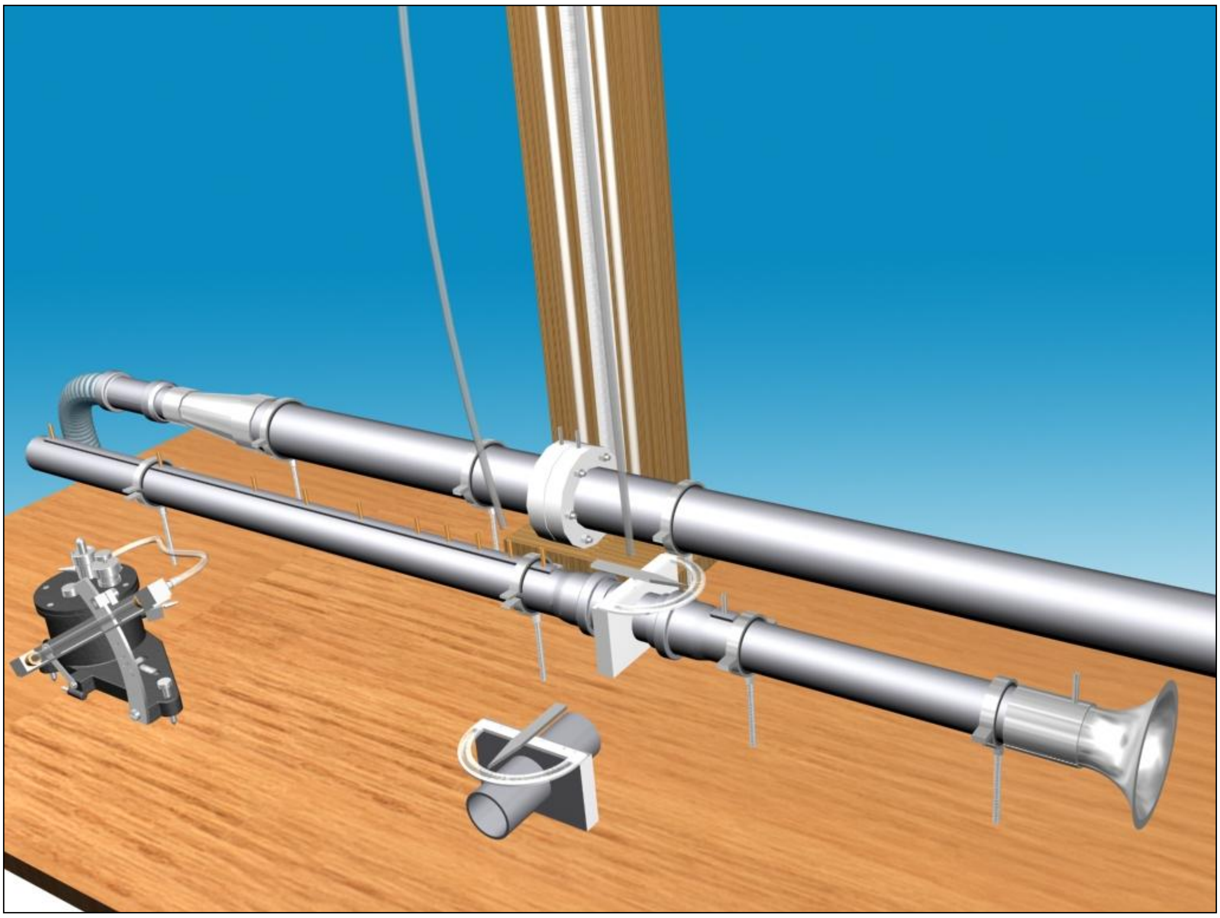


M8

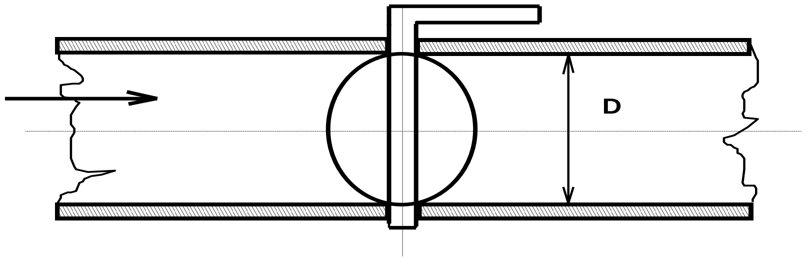
EXAMINATION OF THE LOSS OF VARIOUS TYPES OF BUTTERFLY-VALVES

1. The aim of the measurement

Air flow systems are becoming more and more widespread. Where natural ventilation does not provide enough fresh air, artificial ventilation is needed. In offices, blocks of flats, schools, etc. appropriate ventilation can only be achieved with artificial ventilation. Economical, environmental, mechanical and other aspects suggest it is advisable to install more intake and exhaust points on one operating fan. 20-50 or even a hundred of these points can be installed. The appropriate fresh air distribution is achieved by built in controllers in the pipelines. The built in valves make it possible to shut off single branches, regulate and modify volume flow rates, etc.

In the present exercise we shall examine butterfly-valves that can be built into a cylindrical tube and can be adjusted by the user. The valve is a throttling device that can be adjusted from the outside manually or via a regulating motor. This way we can increase or decrease the diameter of the tube. It can be locked in a particular position. There are types that can close the entire diameter, while others cannot.

An important aspect is how sensitively the valve can regulate the flow rate in the tube. The flow rate usually changes a lot when the valve is opened a bit from a totally closed position, while in a fully opened state a small closing adjustment barely affects the flow rate. (The function is similar to that of a water tap.) Figure 1. is a schematic sketch of a butterfly-valve. The circular valve inside the tube can be adjusted with the lever outside the tube.



1. ábra: Pillangószelep sematikus ábrája

We have provided various kinds of valves for the measurement. The task is to determine the characteristics of these valves. This means determining the loss coefficient as a function of the angle of closure.

What are the characteristics of a butterfly-valve?

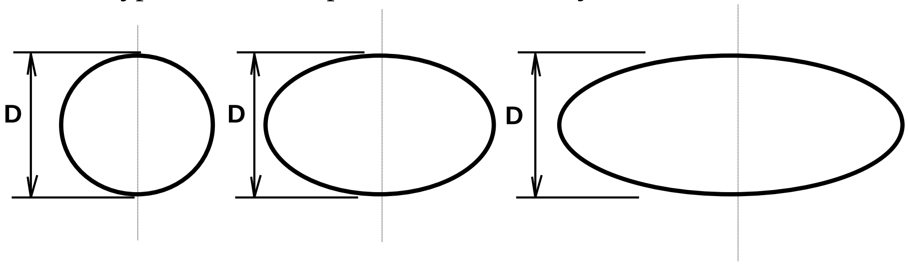
By turning the lever of the butterfly-valve from angle "β" toward a closed state, the loss coefficient of the valve (ζ_{valve}) will change.

Many characteristics are used to describe valves and taps, depending on whether the system is used with water, air, high or low pressure, etc.

We examine the most typical of the characteristics: the change of flow rate as a function of the angle of the valve. The advantage of this characteristic compared to others is that it contains dimensionless factors, so it is independent of a medium and diameter. It is advisable to provide other characteristics, for example the flow rate at a given amount of pressure (e.g. 100 Pa), or the opposite of this, the degree of pressure loss resulting at a given flow rate.

Usually, if we know $\zeta_{valve} = \zeta_{valve}(\beta)$, then most of the other characteristics can be calculated.

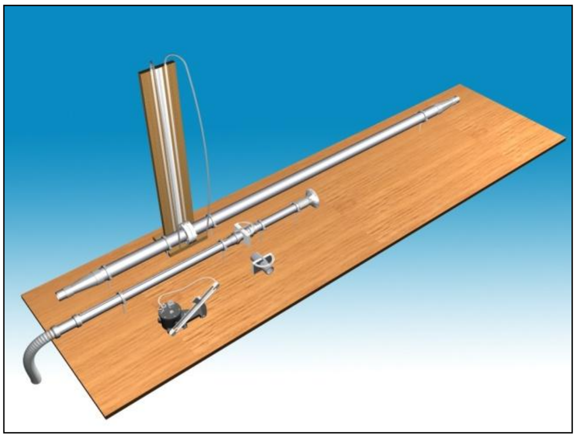
Angle β is zero when the valve is open, the lever of the valve is parallel to the axis of the tube. During the measurement we are going to measure the characteristics of various kinds of butterfly-valves. These have circular and elliptical plates, as seen in the figure below. The flow rate of various types of circular plates can be the object of further examination.

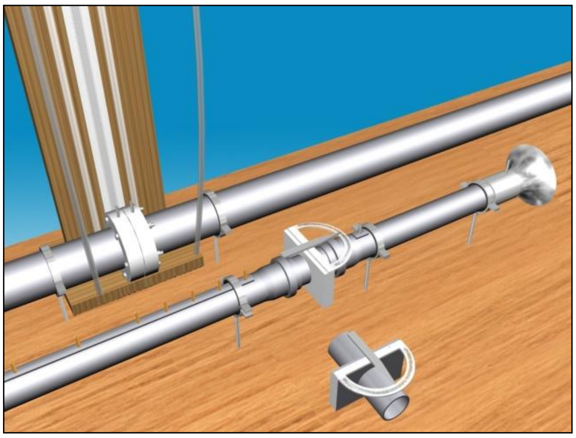


The main objective of the measurement is to measure the various characteristics of butterfly-valves.

2. Description of the measurement device

The components can be measured with the devices depicted below.





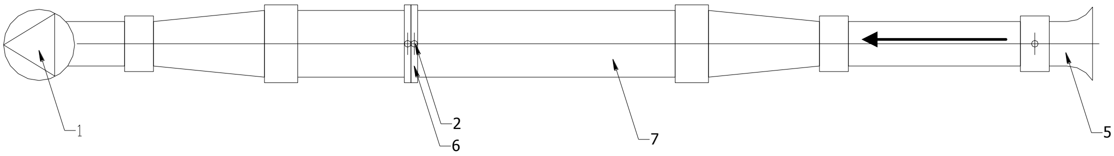


Figure 1: Calibration device

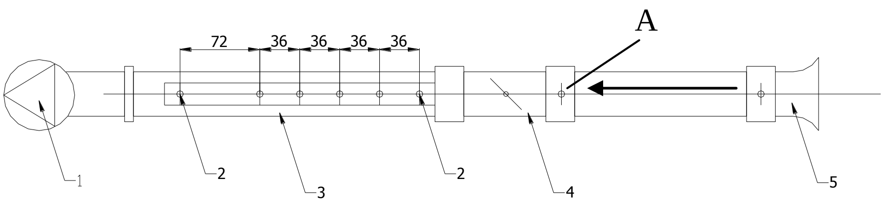


Figure 2: Butterfly valve with a flow rate measuring section

On the measuring tube connected to the inlet of the operating fan (1), we find an inlet orifice plate (5). This serves the purpose of measuring the flow rate of the air flowing through the device. The inlet orifice plate needs to be calibrated before measuring (figure 1). The process of the calibration is described in a later chapter. (Do not cover the hole on the tube connecting the fan to the measurement set-up.)

The inlet orifice plate connects to the tube (4) containing the butterfly-valve. After the inlet orifice plate, but still on this tube, there is a static pressure tap (point A). The measuring section (3) (which contains pressure measurement points) has to be attached to the other side of the butterfly valve. A number of pressure measurement points are needed after the valve, because of the flow separation occurring at even a relatively low valve angle, thus reducing the diameter of the flow. So a relaxation section is needed, where the flow can fill the entire diameter once again. This phenomenon can be measured with the help of the pressure measurement holes. The pressure will increase in the direction of the flow, until the point where the flow fills the entire diameter again. Here it decreases a little due to friction. In the evaluation of the measurement, we have to find the point where the pressure is at its maximum after the butterfly valve (the place of point C). The calculation of the loss coefficient is done by using the pressure difference between point C and point A ($p_A - p_C$).

Note: During the measurement it is practical to measure the pressure difference $p_A - p_C$ right away, and therefore rethinking the above mentioned connections, it can be stated that in the relaxation section, the pressure differences decrease, and reaching a minimum begin to increase. Naturally, if the positioning of the valve is such that there is barely any separation, then the relaxation section is omitted and the pressure is going to continuously increase.

3. The theoretical background to the measurement and the quantities to be measured

Calculation of loss coefficients:

We use the Bernoulli-equation including loss terms to determine the loss coefficient.

The equation is written between point A (the point upstream of the butterfly-valve) and point C (the point after the butterfly valve, where the pressure is at its maximum)

$$p_A + \frac{\rho}{2} \cdot v^2 = p_C + \frac{\rho}{2} \cdot v^2 + \frac{\rho}{2} \cdot v^2 \cdot \zeta_{valve.} + \frac{\rho}{2} \cdot v^2 \cdot \left[\frac{L}{D} \cdot \lambda + \zeta_{pipe} \right]$$

"v" in the equation is the average velocity in the tube.

"$\zeta_{valve.}$" the loss coefficient of the butterfly valve

"L" distance between the two measurement points (not necessarily the distance in the figure. It can also be between two different measurement points)

"D" inner diameter of the tube

"λ" friction coefficient of the tube

"ζ_{pipe}" loss coefficient of the connecting elements

"ρ" density of air

The loss due to friction in the tube, $\frac{L}{D} \cdot \lambda$, and the losses of the connecting elements between the sections are negligible, thus: $\left[\frac{L}{D} \cdot \lambda + \zeta_{pipe} \right] = 0$

We determine the loss coefficient in the equation as $\zeta_{valve.}$

$$\zeta_{valve} = \frac{p_A - p_C}{\frac{\rho}{2} \cdot v^2}$$

The pressures in the equation can be measured on the pressure taps found on the side of the tube (3) via a micro manometer or pressure transducer.

"v" (average velocity) can be calculated from the values measured with the standard orifice plate (6), with regard to the diameter being investigated.

An important task will be the illustration of the pressure distribution after the butterfly valve. Thus, the changes in pressure have to be illustrated with regard to the static tap position. This will also provide information about the flow that is generated after the valve. We will choose the exact position of A and C with the help of these diagrams.

4. Process of measuring

Calibration of the inlet orifice plate

The equation of the volume flow rate through the inlet orifice plate is the following:

$$q_v = k \frac{d_i^2 \pi}{4} \sqrt{\frac{2}{\rho_1} \Delta p_i}$$

Where

k inlet coefficient

d_i inner diameter of inlet orifice plate
ρ_1 density of air
Δp_i pressure drop measured on the inlet orifice plate

The flow factor of the inlet orifice plate can be determined with the calibration tube (figure 1). The calibration tube contains a standardized orifice plate, on which we can measure the flow rate with a standard method. During calibration we have to measure the pressure drop of the standard orifice plate and the inlet orifice plate at different flow rates. The flow rate can be deduced from the pressure drop of the standard orifice plate, which compared to the pressure drop of the inlet orifice plate determines the flow rate in the equation. The determination of the flow factor should be done at three volume flow rates, after which the three results need to be compared. Since the measurement set-up can be set to only small Reynolds numbers (Re) the dependency on the Re cannot be seen and the three values will be similar. Taking the average of the three values for the flow factor, we can now make measurements with the inlet orifice.

Note:
In general, the calibration procedure would require the creation of a calibration diagram from the measurement results. In this case the measured data would always be compared to the diagram to find the actual value of the measured results. This was not necessary in this case, since the calibration could be limited to the one constant's value.

The equation of the flow through orifice:

$$q_v = \frac{C}{\sqrt{1-\beta^4}}\varepsilon_1 \frac{d^2\pi}{4}\sqrt{\frac{2}{\rho_1}\Delta p}$$

where
C Flow coefficient
β Standard orifice plate diameter-ratio (here β=0.6587)
ε Compressibility factor (ε=1, since the pressure change of the medium is small)
d Hole diameter of standard orifice plate (here d=38.8mm)
Δp Pressure drop on the standard orifice plate

Formula to calculate flow component C:

$$C = 0.5961 + 0.0261\beta^2 - 0.261\beta^8 + 0.000521\left(\frac{10^6\beta}{Re_D}\right)^{0.7} + (0.0188 + 0.0063A)\beta^{3.5}\left(\frac{10^6}{Re_D}\right)^{0.3} + 0.011(0.75-\beta)\left(2.8 - \frac{D}{0.0254}\right)$$

where

Re_D the Reynolds number calculated with the diameter before the standard orifice plate (here D=58.9mm)

$$A = \left(\frac{19000\beta}{\mathrm{Re}_D}\right)^{0,8}$$

Iteration
Since the Reynolds number is dependent on the velocity, and the velocity is dependent on the flow coefficient, which is again dependent on the Reynolds number, it is advisable to use iteration to complete the task. The flow coefficient in the first iteration cycle shall be C=0.6.

We shall determine the flow rate at the given flow number, the velocity before the standard orifice plate, the Reynolds number, and finally we shall determine the flow coefficient. From here the cycle starts all over again, and we calculate the flow rate with the new flow coefficient, the velocity, etc. The results converge swiftly and after 2 or 3 iteration cycles we receive the actual results (we can consider the solution converged if the relative difference between the substituted C and the calculated C value is below 1-2%).

1. step

$C' \rightarrow q_V' \rightarrow v' \rightarrow Re_D' \rightarrow C''$

2. step

$C'' \rightarrow q_V'' \rightarrow v'' \rightarrow Re_D'' \rightarrow C'''$

etc.

Determining the mean velocity

We can measure the volume flow rate at a given position of the butterfly valve with the help of the inlet orifice plate. Mean velocity can be determined from the flow rate:

$$v = \frac{q_v}{A}$$

q_v volume flow rate

A intake area of the orifice plate

A "ρ", the density of air, can be calculated as follows:

$$\rho = \frac{p_0}{R \cdot T}$$

where p_0 is the atmospheric pressure, $R = 287 \frac{J}{kg \cdot K}$ and T is the current room temperature in Kelvin.

5. Evaluation of the results:

The measurement should be done with at least three types of butterfly valves. The loss coefficient should be determined for at least every 10 degrees with regard to the angle of the butterfly valve. The measurements can deter from this near the entirely open valve measurement points, where the characteristics of the valve slowly change (ex. 15 degrees) and near the entirely closed position, where the characteristic changes abruptly (ex. 5 degrees).

- In the evaluation the characteristics of the butterfly valve the loss coefficient should be illustrated in a diagram. (x axis: β angle, y axis: ζ_{valve}) The “open” state should belong to $\beta = 0$.

- The pressure distributions, which were measured parallel to the axis, should be illustrated for at least three characteristic angles in the case of each valve.

Error calculation:

The butterfly-valve loss coefficient and its absolute error:

$$\zeta_{valve} = \frac{\Delta p_{tot}}{\frac{\rho}{2} v^2}$$

Expressed with the measured values: absolute error: relative error:

$$\zeta_{valve.} = \frac{\Delta p_{tot}}{k^2 \cdot \Delta p_i} \qquad \delta\zeta_{valve} = \sqrt{\sum_{i=1}^{n}\left(\delta X_i \cdot \frac{\partial \zeta_{valve}}{\partial X_i}\right)^2} \qquad \frac{\delta\zeta_{valve}}{\zeta_{valve}} = ?$$

where X_i are the measured values and the related errors:

$X_{1,2}=\Delta h$ $\delta\Delta h=0.001m$

Or

$X_{1,2}=\Delta p$ $\delta\Delta p = 2\ Pa$

The calculated errors need to be applied to the results in the tables and the diagrams. (ex. $\zeta_{valve} = \#\pm 0.1$)

Remember that during the labs:

- Before turning any measurement device on, or in general during the lab, make sure that safe working conditions are ensured. The other participants have to be warned of the starting of the machines and of any changes that could endanger the members of the lab group.
- The atmospheric pressure and room temperature should be recorded before and after every measurement.
- The measurement units and other important factors (e.g. data sampling frequency, date of calibration) of every recorded value of the applied measurement devices should be recorded.
- Type and construction number of the applied measuring instrument should be included in the final report.
- Checking and harmonizing of the units of the recorded values with those used in further calculations.
- Manometers should be calibrated if necessary.
- The measurement ports of the pressure meter should be carefully connected to the correct pressure ports of the instrument.
- If inlet or outlet tubes are to be assembled with fans, connections should be airtight as escaping/entering air can significantly modify the measurement results.